THE INTERACTION OF MAN AND AQUATIC ECOSYSTEMS

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INTRODUCTION

Water is the basis of all life. Therefore, aquatic ecosystems are essential segments of the environments of man. They are among his primary resources. Populations have invariably developed in close proximity to water -- oceans, estuaries, rivers and lakes.

Lakes, to be emphasized in this paper, are used for municipal and industrial water supplies, domestic and industrial waste disposal (directly or indirectly), recreation (including swimming, boating and fishing), commercial fisheries, shipping, coolant and water supply source for thermal and hydroelectric generating stations, respectively, and a source of water for irrigation and livestock. Thus lakes and their associated streams play a vital multiple-use role in man's diverse activities and are influenced in turn by these activities.

The study of lake ecosystems, limnology, involves, basically, the causal relationship of biotic communities to their environments including the interassociation of organisms or, in essence, aquatic biology. In addition to biology limnology is concerned with chemistry, physics, geology, geography, and meteorology since a comprehensive knowledge of the environment is essential to a real understanding of an aquatic ecosystem. This study is not restricted to the aquatic ecosystem itself but must involve the nature of the surrounding terrestrial drainage basin in which the water body is located.

"Lakes are geologically transitory, usually born of catastrophes, to mature and die quietly and imperceptibly" (Hutchinson 1957). Lake basins originate mainly from glacial or tectonic action. Their natural life span is largely dependent on the geological-vegetational nature of the lake drainage basin and the meteorological forces acting thereon. Through natural forces a lake will gradually fill in with sediments which are allochthonous (from outside the lake basin) or autochthonous (produced biologically or chemically within the lake basin). Thus the natural life span of Lake Erie has been estimated as approximately 50,000 years.

Whenever man has appeared on the scene his activities have speeded up the aging process, a process which has been referred to as eutrophication. Eutrophication involves an increase in the rate of nutrient input with a subsequent increase in the rate of production within a lake. This increased production at the primary level is not accompanied by a parallel increase in consumption. Increased rates of sedimentation result, speeding up the rate of lake aging. Lake Erie has aged 15,000 years during the last 50 years as an effect of man's influence.

THE EFFECTS OF EUTROPHICATION

Advanced stages of eutrophication are quite obvious with respect to effects. Luxuriant growth of algae and macrophytes results. Algal blooms and accumulation of scums along the shores occur. Decomposition with attendant unaesthetic effects decrease the value of beach properties and discourage recreational pursuits associated with water. Fish kills may result through oxygen depletion in restricted bays in summer or under the ice in winter. In either case, decomposition of algae and macrophytes depletes oxygen. Interference with water supplies may result in reduction of filtration rates and the production of taste and odor problems. Occasionally serious losses of livestock occur due to toxic blue-green algal scums (Hammer 1968). However, incipient eutrophication is more difficult to detect since it is often dependent on local conditions initially.

INDICES OF EUTROPHICATION

A quantitative increase in plant biomass, either pelagic phytoplankton or macrophytes, occurs. Associated with the increase in biomass is an increase in primary production rates. Certain algal species,notably blue-green algae such as Oscillatoria rubescens, Aphanizomenon flos-aquae and Microcystis aeruginosa are often dominant members of an eutrophic ecosystem. In the upper Qu'Appelle River system, during the 1960's, all the lakes except Last Mountain Lake were characterized by high aquatic production and biomass and a dominance of the last two species of algae.

Faunal changes are also characteristic of the eutrophication process. The changes include a gradual decrease in the number of coregonids and an increase in coarse fish such as cyprinids. These changes have occurred in Lake Constance and in Lake Erie. In spite of planting game fish extensively in the upper Qu'Appelle lakes, buffalofish, common suckers, and more recently, carp, have become the most common fish. As with plant biomass, animal biomass increases. Practical use is made of this in many parts of the world where ponds are fertilized and hugh crops of fish are harvested -- an ave: of 2200 kg per hectare in Israeli fishponds (Macan 1969). In spite of large animal biomass the imbalance between production and consumption continues to widen as eutrophication increases.

Chemical conditions have often been used as indicators. The decline of oxygen content in the hypolimnion in summer is an index restricted to deeper stratified lakes. Total dissolved solids, and ions such as sulfate, chloride, sodium, potassium, calcium and magnesium tend to increase with time but are relatively stable seasonally. These parameters are of little use in the shallow lakes of the Qu'Appelle River system because the amount of runoff and precipitation varies considerably. The lakes may vary from practically closed in one year to excessive flood and flow-through conditions another year.

Physiologically, nitrogen and phosphorus are more important in primary production and therefore serve as better indicators. These substances frequently occur in limiting quantities. This is well known in agricultural practices. Sawyer (1947) suggested that "well-behaved lakes" have 15 μg/l or less P (PO_4) and 300 μg/l or less inorganic nitrogen in the water. Vollenweider (1968) stated that "total P loading in excess of 0.2-0.5 $g/m^2/yr$ coupled with a total N loading of 5-10 $g/m^2/yr$" indicates potentially serious eutrophication. Obviously mean depth of the lake plays an important role as shallow waters can receive much lower loadings than deeper lakes. In addition internal loading from nutrients exchanged from the sediments is more effective in shallow lakes where wind action plays an important mixing role.

THE PROCESS OF EUTROPHICATION

Natural eutrophication occurs wherever lakes exist. It is a gradual accumulation of nutrient salts by solution from the soils and rocks of the watershed. It would include deposition by wildlife, mainly aquatic birds, e.g., aquatic birds which feed off the lake contribute 12% of the phosphorus entering Klamath Lake, Oregon (Miller and Tash 1967). The natural rate of accumulation of nutrients and subsequently sedimentation is very slow.

Artificial eutrophication, attributable to the presence and activities of man, increases the rate of eutrophication. If the concentration of people is rapid, associated phenomena, particularly during the last three decades, produce what is termed "rush eutrophication" -- a rapid acceleration of the natural process of aging.

What are the substances which contribute to lake enrichment and subsequent excessive growth ? Many substances have been found to be limiting with respect to algal growth in undisturbed natural situations. These include the elements C, N, P, Fe, Mo, Mg, Na and vitamins B_{12}, thiamin and biotin, for example. In many lakes which man has influenced considerably, nitrogen and phosphorus have often been held responsible for the various manifestations of advanced eutrophication.

In studies of algal bloom problems in the upper Qu'Appelle lakes, I found a direct correlation between orthophosphate concentration and the biomass of the blue-green algae Aphanizomenon flos-aquae (the most abundant nuisance alga in the lakes) and Microcystis aeruginosa as well as with total organic plankton biomass (Hammer 1969). In one way this is not surprising as Warwick (1967) found that the Qu'Appelle River deposited annually 196 metric tons of soluble $P(PO_4)$ and 34 metric tons of nitrate nitrogen into Pasqua Lake. This is equivalent of 9.8 g $P(PO_4)/m^2/yr$ and 1.7 g $N(NO_3)/m^2/yr$ which far exceeds the critical loading level for a lake of mean depth 5.6 meters. The heaviest blooms also occurred in Pasqua Lake associated with the highest orthophosphate concentration. No relationship with nitrogen was found. Stewart (1968) concluded that all heterocyst-bearing blue-green algae have the capability of fixing nitrogen and Aphanizomenon is one of these algae.

THE SOURCES OF NUTRIENTS

Diffuse sources of nutrients are: (1) natural sources of nutrients included in runoff from mountains, woodlands and grasslands and would include biological sources such as leaf fall as well as nitrogen fixation by blue-green algae and bacteria,(2) artificial sources which involve human activities directly or indirectly. Three general categories, fertilizer application to increase crop production, the livestock industry and atmospheric fallout particularly near industrial centers, contribute nutrients.

Commercial fertilizers came into use in Europe about 1850. Requirements have steadily increased so that growth trends in useage have almost been exponential (11% N, 3-4% each for P_2O_5 and K_2O yearly). The application of livestock manure to farm fields has long been practiced. Bodies of water receive nutrients from farmland through leaching and run-off. Nitrogen compounds leach relatively easily while phosphorus tends to be bound to the soil and is therefore lost mainly through run-off and erosion. Spring run-off waters in the Qu'Appelle River region contained 0.28-1.75 mg/l N (NO_3) (mean 0.94) and 0.09-0.38 mg/l P (PO_4) (mean 0.21) during April 1967 (Hammer 1970). In the Lake Blackstrap area near Saskatoon these levels were 0.70-1.50 mg/l N (NO_3) (mean 1.15) and 0.01-0.46 mg/l P (PO_4) (mean 0.27) during April of 1969. It is interesting to note that there is little algal growth or phosphate in Lake Diefenbaker or in the Broderick Reservoir of the Saskatoon Southeast Water Supply System. However, the next reservoir, Brightwater, is high in phosphate and full of algae. The drainage basin for Brightwater is the rich agricultural area west of Kenaston and Hanley which drains into the reservoir via Beaver Creek. The effects of this enrichment appear subsequently in Lake Blackstrap. Klamath Lake, Oregon, receives only 5% of its total influent from agricultural drainage yet 20% of the nitrogen and 26% of the phosphorus which enters the lake originates in agriculture (Miller and Tash 1967).

Livestock contribute 8 times as much nitrogen and 10 times as much phosphorus as the human population in Europe. No particular problem exists with livestock on the range. If, however, they are confined more and more in feedlots in the name of efficiency and profitability, localized problems exist. Since one cow has a pollution equivalent of 10-15 humans a feedlot of 10,000 head becomes equivalent in effluent production to a city the size of Saskatoon. Winter spreading of manure on frozen fields results in most of the nutrients being washed off in spring run-off waters (Biggar and Corey 1969). Although this fact has been well documented for more than a decade the University of Saskatchewan, Saskatoon, still blithely carries on this obnoxious procedure.

McCarty et al.(1966) claim that agricultural run-off is the greatest single contributor of nitrogen and phosphorus to water supplies in the Mississippi-Missouri drainage system. Udall, U.S. Secretary of the Interior, recommended in 1968 that the United States spend 5 billion dollars over the next five years to clean up and reduce agricultural pollution of the waters of that country. More than two-thirds of the sum was recommended for erosional control. Fish (1969) concluded that agricultural development is the most important cause of eutrophication of lakes in New Zealand. In Saskatchewan, an area of relatively low rainfall, one would expect the amount of nutrients contributed by agriculture to be less than in areas of high rainfall. Cited application of about 100 pounds per acre on Saskatchewan agricultural lands (Committee Sask. Inst. Agrology 1971) is equivalent to useage in the United States which is the highest average in the world (Vollenweider 1968). It is obvious from this alone that the potential danger to water bodies is as great as that already proven in the United States.

Atmospheric fallout contributes significant amounts of inorganic material particularly near industrial centers. The values are sufficiently high that they must be considered seriously. In Saskatchewan, our industries and cities almost certainly exert little impact on lakes in this respect.

Point sources (domestic sewage and industrial waste) are easier to examine and treat than diffuse sources. Contributions of phosphorus and nitrogen per person per day have been calculated for treated and untreated sewage. These values are used to determine permissible disposal for each kind of treatment -- primary, secondary or tertiary. The problem of disposal increases with an increasing population. In Saskatchewan, the Water Resources Commission has, over the last several years, required urban areas to institute sewage treatment and improve on it in future years. At the present time the reduction of nutrients by the lagoon methods of treatment used in the province is negligible while the Saskatoon primary treatment removes about 35%.

Detergents are a major source of phosphate today. Prior to the federal required limitation to a maximum of 20% phosphate in detergents, 40% of the phosphate contributed to lakes Erie and Ontario had its source in detergents (Dept. Energy, Mines and Resources 1970). It is likely that this figure was true across Canada but has declined considerably since then.

Industries produce effluents with varying quantities of nutrients. The highest loadings come from yeast, sugar and starch production, distilleries, wood processing plants, abbatoirs, textile and synthetic fiber plants. Distilleries produce up to 1900 mg N/liter while beet sugar factories produce up to 274 mg P/liter in their effluents (Müller 1966). In Saskatchewan a number of industries probably contribute significant amounts of nutrients to surface water systems. Since these effluents are generally combined with domestic waste in urban systems it is more difficult to estimate the contribution of each industry.

Warwick (1967) calculated that the cities of Moose Jaw and Regina (population ca. 150,000) contributed 196 metric tons of soluble phosphate phosphorus and 34 metric tons of nitrate nitrogen annually to Pasqua Lake. Most of this loading probably stems from domestic sewage including detergents.

CONTROL OF EUTROPHICATION

Fluctuations in the eutrophication process over time (Horie 1969) offer some hope that the process can be turned back or at least slowed down to a minimal rate of increase. To ensure ultimate success the cooperation of governments (federal, provincial and municipal), industries and the public is a necessity. Governmental control is required. Drainage basin control systems are the most effective in dealing with control of eutrophication and pollution.

The reduction of nutrients in domestic sewage and industrial wastes would have immediate results in decreasing eutrophication. Tertiary treatment of sewage has been found to be effective particularly with respect to phosphorus removal and would reduce the nutrient input into the Qu'Appelle River system by at least 50%. Further removal of phosphate from detergents would also lead to improvement.

One method that has not been used on the prairies is the use of sewage effluent for irrigation. Melbourne, Australia, has used this method for 80 years and it is remarkably successful. The city has a 42 square mile farm in a 19" annual rainfall area. The raw sewage is used to flood 20 acre pastures to an average depth of 4 inches every 18 days. The surplus water is removed by drains. Once the pasture is dry, cattle and sheep are grazed. This process is carried on during the high evaporation period of September to May. During the low evaporation period grass filtration is used after sedimentation in tanks. Lagoons are also used for excess sewage. The sewage of almost 2 million people is treated in these various ways. Up to 19,000 two-year old cattle and 40,000 sheep are marketed each year. The net cost per person for sewage treatment is 62¢ annually. There is no reason why this system couldn't be used in Saskatchewan during May through September.

Not only is it practically feasible but it would also be economically beneficial.

Other biological means of nutrient removal are being perfected. The growing and subsequent harvesting of algae is one of these methods. Although valuable as protein food the process is too expensive with present day techniques. Up to 30 tons dry weight/acre/year have been harvested from sewage ponds in California and used in livestock feeds.

In general the technology for dealing with point sources of nutrients is well developed. It requires considerable financing and continuous costs to institute the necessary works. Government support and control are essential. Diffuse sources are much more difficult to control and more dependent on public cooperation initially. This applies particularly to the agricultural sector.

Feedlots may be treated as point sources. Their location with respect to streams is critical. Recent steps by the Water Resources Commission with respect to requiring permits prior to the establishment of feedlots is essential. However, established feedlots should also be reexamined using the new criteria. Field spreading of manure is the most economical method of disposal and is also economically and agriculturally beneficial. Other techniques such as lagooning, incinerating and dehydration are also feasible when field spreading is not.

The greatest single problem is related to land fertilization and erosion and the subsequent effects on water systems. The annual burning of stubble still widely carried out in Saskatchewan must be terminated. It can only lead to erosion and loss of soil fertility. Fertilizers must be applied at the proper rates using correct methods of application. Although tillage practices have improved tremendously over the last several decades, strict attention must continue to be paid to further improving methods and thus reducing erosion.

If one of the problems of agriculture is that phosphorus is rapidly bound to the soil, perhaps extensive research should be carried on into methods of releasing this phosphorus for plant growth rather than applying still more. It is the responsibility of the agricultural industry to reduce their pollutional effects on our aquatic systems (as well as the atmosphere). Inability or unwillingness to do so will undoubtedly result in more and more governmental control.

PESTICIDES AND HEAVY METALS

The contamination of the environment with pesticides has been much publicized lately. Many pesticides are highly toxic to man and some are extremely persistent in the environment. More serious is the fact that they are being used in ever increasing quantities and varieties. Adequate testing by various control agencies becomes more difficult and especially so under poor economic conditions when the necessary staff cannot be employed. A good case in point is the importation of lannate to control the bertha armyworm outbreak in Saskatchewan in the fall of 1971. Little was apparently known about this pesticide and its side effects. According to some entomologists there is also some doubt about its value to control the outbreak in question. Another good example of the inadequacy of the testing and approval program is the case of dieldrin. Only ten years ago the government of this province purchased and sold the insecticide for control of grasshoppers. A few years later its use was banned.

Pesticides enter waters in much the same way as the nutrients we have already discussed. In addition they may also enter via the atmosphere through wind drift and careless application. The direct application of pesticides to control aquatic macrophyte and algal growth and in eliminating rough fish populations (as practiced by the Sask. Fisheries Branch) is another major source of contamination of waters.

The greatest problems with pesticides have involved massive killing of fish and birds including interference with bird reproduction. The latter has been exemplified in the drastic reduction of species such as the prairie falcon and the golden eagle to the point where they are on the world's endangered species list. The greatest hazard stems from the organochlorine compounds such as DDT, dieldrin and endrin. These poisons tend to persist in the environment (aquatic and terrestrial) at low concentrations. However, they are accumulated at the lowest levels of the food chain and biologically concentrated at each subsequent trophic level. This biological magnification results in high concentrations of the pesticide in the fat and brain tissues of fish and birds which are at the end of the food chain. The effect is further magnified in man if he consumes sufficient quantities of foods that have high concentrations. This is exemplified in the fact that human milk in some parts of the United States has 2 to 6 times the amount of DDT permitted in cow's milk offered for human consumption.

Most of the problems with agricultural pests stem from the conversion of agriculture to a series of monocultures. This encourages the vast proliferation of species of insects which tend to be crop specific. Unfortunately man has to date not yet learned to develop species specific poisons since most pesticides are broad spectrum biocides. Perhaps the present call for crop diversification will also reduce the requirements for ever increasing use of pesticides.

Another major cause for alarm in relation to concerns for human health has been the problem of heavy metals, mercury in particular. Mercury has been used for seed treatment as a fungicide, as a fungicide in some pulp mills (particularly in Sweden) and in chlor-alkali plants. The acute effect of mercury poisoning through eating contaminated fish was first demonstrated in Japan during the 1950's. Subsequently Sweden became so alarmed at high concentrations in fish that the agricultural use of mercury was investigated and soon banned. Contrary to recent reports in Saskatchewan they (Löfroth 1970) found considerable translocation from treated seed to ensuing crop and then into meat and eggs. Investigations of North American fish populations showed very high concentrations of mercury in fish downstream from chloro-alkali plants, e.g., Saskatchewan River downstream from Saskatoon. Concentration is carried on by organisms such as fish and mollusks directly although there is some biological magnification. Recent work indicates that other metals such as cadmium are not likely to be accumulated to any extent by aquatic life.

As far as humans are concerned the acute effects of pesticides and heavy metals are fairly well known. The number of deaths or severe effects produced by these substances are probably far less than the number of motor vehicle deaths each year in this province. The area which poses the greatest problem is that of chronic effects of these substances. What is the long term effect of a certain concentration of DDT or mercury in human tissue?

THE PROBLEM OF MANAGEMENT

The growth of population, industrialization and the increased demands on the natural resources to increase the standard of living and to support life itself have affected water resources to the same degree that they have affected other resources. These pressures have created a need for more effective management as well as more intensive management. We can no longer leave the solution of the problems that arise exclusively to the engineer. The need today is for interdisciplinary approaches to the solution of what are very compl problems which have ramifications throughout society. We must use the tools of biology, ecology, economics, education , hydrology, limnology, pedology, poli and legal institutions, sociology and technology to attain the objectives that society must establish.

This paper has attempted to show how terrestrial and aquatic systems are interrelated. Whatever man does to the terrestrial system is reflected in aquatic systems and usually with deleterious results. The effects of aquatic systems on terrestrial ones are not as obvious. However, residents of terrestrial systems make rather diverse uses of aquatic systems, including water for domestic use, for irrigation, for waste disposal, for power development and so on.

It is obvious then that lakes and streams must be considered as part of a larger system if successful management is to be achieved. The systems approach permits a much broader basis for delineating the problems confronting society and the formulation and examination of a wider range of alternative solutions for these problems. In addition, areas for potential research are more easily identified.

The system would have to contain three major subsystems. The physical subsystem has been extensively discussed earlier in this paper. It would have to be defined on a regional basis generally involving a whole drainage basin. In some cases it might have to involve several basins. The latter situation arises when a consideration must be given to diversion of water from one basin into another, e.g., South Saskatchewan basin water into the Qu'Appelle basin to satisfy domestic and other requirements.

A second subsystem would include all the biota in the various componen of the physical system including the aquatic medium. The interactions of the physical subsystem and the biological subsystem come into play here. Value judgements must be made as to the long term effects of specific interactions and, if necessary, manipulations based on the best information available at that time must be instituted. These decisions impinge directly on and interrelate with the third subsystem, the social one. The nature of this subsystem determines what the problems are, what has caused them and what their solutions will ultimately be. Since it involves man directly it is the most difficult area of decision-making and the application of technology.

From the standpoint of research management we must first of all order the problems of a particular system. Water quality would rank high on the priority list although water quantity in a relatively dry region such as ours would also rate high and would tie in closely with water quality.

From a systems point of view with regard to water quality the first requirement would be a nutrient budget for the system in question. Such a nutrient budget is now being completed for the Qu'Appelle River Basin. It should delineate the kinds and quantities of nutrient input and their various sources. Management must then decide what can be done to alleviate the problems which have been enunciated earlier as the result of previous research (Hammer 1970). Priorities must be established on the basis of the solutions which offer the most benefit but are not necessarily the most economical. The education of the public plays an important role in establishing priorities and securing public cooperation in financing beneficial solutions.

As a limnologist, my first order of priority would require tertiary treatment of the sewage (or its use in irrigation) from Moose Jaw and Regina. This is the largest single source of nutrients for the Qu'Appelle system. This would undoubtedly improve the water quality and produce some relief with respect to the algae problem. It would not, in itself, solve the problem. The source of other nutrients is too high.

Dilution of sewage, and therefore nutrients, has been a solution engineers have always used. What would happen if water were diverted from Lake Diefenbake into the Qu'Appelle system -- interbasin diversion? The effects of this diversion have already been evident in Buffalo Pound Lake. Total dissolved solids have been halved resulting in a better quality water for domestic supply. The phosphate phosphorus levels have been reduced there to about one-tenth their previous levels, i.e., to 0.03 mg/l. The algae problem has been greatly reduced in this lake during the last two years. However, the lake sediments contain tremendous amounts of the various nutrients. What implication do they have for algal growth in the future?

Can this dilution solution be applied to the lakes below Buffalo Pound Lake? Without tertiary treatment of domestic sewage from the two cities little effect would be likely. The channel capacity of the Qu'Appelle River is extremely limited. Larger throughputs of water would flood the valley and sweep further nutrients into the system. Generally algae populations have increased following extensive spring flooding. I would conclude that little real benefit would result from this approach.

This takes us to the agricultural problem. What if the valley proper were taken out of agricultural production? Would this be beneficial with respect to the lakes? Undoubtedly this production contributes to the nutrient content of the lakes through irrigation return waters and through livestock feedlot operations, small scale though they are. However, agricultural use may be beneficial in that crops will take up nutrients from lake or flood water in products such as hay. If these crops are re-used within the valley the nutrients will only be recycled and will potentially return to the lakes. One would have to know what the actual nutrient balance of agriculture was in the system to be able to make an objective decision. It may be that the best use that the valley could be put to would be to convert it to a park.

I am sure that the agricultural contributions from outside the valley proper have much more influence on the lakes than those within the valley. The problem that must be contended with is that of runoff, the proper use of fertil and care in the disposal of effluent from feedlots. This appears to me to be largely a problem of education and wise guidance on the part of management Good farming practices are essential to prevent water pollution. It may be necessary to build more dams to prevent runoff from reaching lakes with multi-purpose functions. A good case in point is the runoff from farmland which reaches Brightwater Lake. Appropriate impoundments of this runoff could be beneficially used for irrigation and stock watering rather than losing it into the Saskatoon Southeast System and reducing the recreational value of Blackstrap Lake.

What are the research needs with respect to this entire problem? Although considerable research has been carried on elsewhere no investigations have been made into the recycling of nutrients from the lake sediments in Saskatchewan lakes. This research really involves chemists and bacteriologists working as a team. This is a major area for limnological research. The soil scientist must do more research on making available nutrients already in the soil rather than just advising the application of more and better inorganic nutrients. Hydrologists and engineers must carry on research to reduce the amount of land runoff to a minimum. More nutrient balance studies are essential. We have to know the nutrient potential of natural environments as well as the sources that man manipulates and contributes to. Research on the biota of lakes and streams has really only scratched the surface in this province. Greater knowledge of the life cycles of important species, how these life cycles may be adjusted or interrupted by varying the physical or biotic environment and how we might utilize the biotic system to its optimum given a particular situation. Extensive research on the recycling of waste must come high on the list of priorities. It seems almost obscene that we pour nutrients into the lakes and oceans and that we must import inorganic nutrients in order to maintain the productivity of our farmland.

Society at large must, in the future, demand less from the environment and put more back into the environment. Only in this way can we achieve maximum benefits for all not necessarily in terms of economics but more in terms of optimal human well-being. The policy decisions must be made by society as a whole rather than by groups with restricted interests. These decisions must be based on an informed society and this information must derive from intelligent research on a broad interdisciplinary front.

LITERATURE CITED

Anonymous. 1970. The Control of Eutrophication. Dept. of Energy, Mines and Resources, Ottawa (Canada), Inland Waters Branch Tech. Bull. 26.

Biggar, J.W. and R.B. Corey. 1969. Agricultural drainage and eutrophication, 404-445. In Eutrophication: causes, consequences, correctives. National Academy of Sciences, Washington, D.C.

Committee Sask. Inst. Agrol. 1971. Pollution and agriculture in Saskatchewan. Saskatchewan Institute of Agrologists. 28 p.

Fish, G.R. 1969. Lakes: The value of recent research to measure eutrophicatior and to indicate possible causes. J. Hydrology (N Z) 8: 77-85.

Hammer, U.T. 1968. Toxic blue-green algae in Saskatchewan. Can. Vet. J. 9: 221-229.

Hammer, U.T. 1969. Blue-green algal blooms in Saskatchewan lakes. Verh. Internat. Verein. Limnol. 17: 116-125.

Hammer, U.T. 1970. An ecological study of bloom species of blue-green algae in lakes of the Qu'Appelle River System, Saskatchewan. Saskatchewan Research Council, Saskatoon, Sask. 188 p.

Horie, S. 1969. Asian lakes, 98-123. In Eutrophication: causes, consequences, correctives. National Academy of Science, Washington, D.C.

Hutchinson, G.E. 1957. A treatise on limnology. I. Geography, physics and chemistry. John Wiley and Sons, Inc., New York. 1015 p.

Löfroth, G. 1970. Methylmercury. A review of health hazards and side effects associated with the emission of mercury compounds into natural systems. Bull. 4 (2nd edn.) Ecol. Res. Comm., Swedish Natural Sci. Res. Council, Stockholm, 56 p.

Macan, T.T. 1969. General Secretary's Report, Societas Internationalis Limnologiae. Verh. Internat. Verein. Limnol. 17: 2-21.

McCarty, P.L., J.H. Hem, D. Jenkins, G.F. Lee, J.J. Morgan, R.S. Robertson, R.W. Schmidt, J.W. Symons and M.W. Trexter. 1966. Sources of nitrogen and phosphorus in water supplies. Presented to: American Water Works Assoc. Annual Conference, May 22-27, 1966. Bal Harbour, Florida. 40 p.

Miller, W.E. and J.C. Tash. 1967. Interim report, upper Klamath Lake studies, Oregon. FWPCA Publication WP-20-8. 37 p.

Müller, G. 1966. Treatment of mixed domestic sewage and industrial waste waters in Germany. Publ. O.E.C.D., Paris. 113 p.

Sawyer, C.N. 1947. Fertilization of lakes by agricultural and urban drainage. J. New England Water Works Assoc. 61: 109-127.

Stewart, W.D.P., G.P. Fitzgerald, and R.H. Burris. 1968. Acetylene reduction by nitrogen-fixing blue-green algae. Archiv. für. Mikrobiologie 62: 336-348.

Vollenweider, R.A. 1968. Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication. Organization Economic Co-operation Development, Paris. DAS/CSI/68.27, 159 p., 33 figs.

Warwick, W. 1967. Some chemical and biological aspects of water pollution in a portion of the upper Qu'Appelle River System. M.Sc. Thesis, Dept. of Biology, Univ. Saskatchewan, Saskatoon. 174 p.